MULTI-FREQUENCY T-SLOT LOADED ELLIPTICAL PATCH ANTENNA FOR WIRELESS APPLICATIONS

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ABSTRACT:

In this paper, a multi frequency microstrip antenna(MSA) for wireless applications is designed. The proposed MSA comprised of elliptical patch antenna with T-slot. This antenna is fed by coaxial probe. The design parameters are major and minor axis of elliptical patch, length and width of T-slot and feeding point of probe. The proposed antenna can provide optimized multi frequency by varying the above design parameters. FR-4 substrate with dielectric constant 4.4 is chosen. The multi frequencies are 1.57 GHz, 1.96 GHz and 3.4 GHz which covers the applications such as GPS, 4G LTE and WiMAX. The simulation of the antenna is performed using the ANSOFT HFSS and it is analyzed for S_{11}(dB)and radiation pattern. The prototype antenna is fabricated for optimized dimensions and tested using vector network analyser. Simulation and experimental results are compared with each other.

KEYWORDS:

Elliptical patch antenna, T-slot, coaxial feed, multi-frequency.

1. INTRODUCTION:

The microstrip antenna(MSA) is one of the most preferred antenna structures for wireless applications and handheld devices. They are small in size, light weight and low volume. Generally, the multi-frequency MSA are divided into two categories: i) multi-resonator antennas and reactively loaded antenna. In the first category, the multi-frequency operation is achieved by means of multiple radiating elements, each supporting strong currents and radiation at its resonance. It includes the multilayer stacked-patch antennas using circular, annular, rectangular and triangular patches [1] [2]. A multi-resonator antenna in coplanar structures can also be fabricated by using aperture-coupled parallel microstrip dipoles[3]. As these antenna structures usually involve multiple substrate layers, they are of high cost. Large size is another drawback of the multi-resonator antenna, which makes it difficult for the antenna to be installed in hand-held terminals. The second category is reactively load MSA, to obtain multi frequency operation of the antenna such as multi-slotted patch, rectangular patch with two T-slots, truncated circular patch with double U-slot, square spiral patch antenna and pi-shaped slot on rectangular patch [4-

9]. These structures involve complex calculation, design, higher frequency ratio and lower bandwidth as compared to proposed antenna. Therefore, the proposed antenna consists of a simple T-slot which is loaded on the elliptical patch antenna and it is fed by coaxial probe. The dimensions of the proposed antenna are optimized using HFSS in such a way that it provides multi-frequency.

The paper is organized as, antenna design is discussed in section 2, followed by simulation and experimental results in section 3 and 4 and section 5 concludes the paper.

2. ANTENNA DESIGN:

The proposed antenna is shown in Figure 1 (Top view) and Figure 2 (Side view). The elliptical patch of semi major axis ‘a’ and semi minor axis ‘b’ is printed on the FR-4 substrate (ε_r=4.4). A T-slot of length ‘l’ and width ‘w’ is slotted in the elliptical patch.

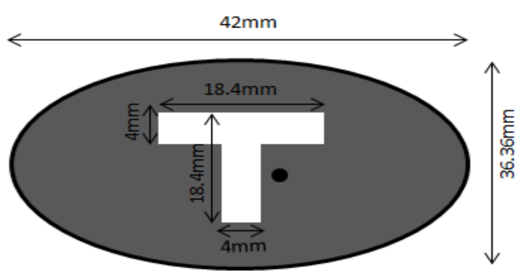

Figure 1: Top view of proposed antenna

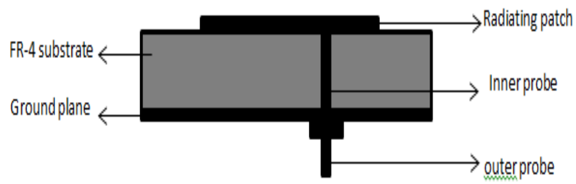

Figure 2: Side view of proposed antenna

The resonant frequency of elliptical patch is given as [10],

$$f_r = \frac{c\sqrt{q}}{\pi a e\sqrt{\varepsilon_r \varepsilon}} \quad \text{-- (1)}$$

where, c is Velocity of light, ($3*10^8$ m/s)

e is eccentricity of elliptical patch as,

$$e=\sqrt{1-\left(\frac{b}{a}\right)^2} \quad \text{----- (2)}$$

where, ‘a’ is the Semi major axis of the elliptical patch.

‘b’ is Semi minor axis of the elliptical patch.

ε_r is dielectric constant of the substrate.

q is the exact value of the parameter q for given mode and eccentricity is calculated as [11],

The order of few modes of elliptical patch antenna is TM_{11} and TM_{21} is based on the q value function. In this paper, TM_{11} mode is chosen. Then the q value for TM_{11} mode is given as,

For interval e (0.0, 0.4),

$$q_{11}=0.847e^2 - 0.0013e^3 + 0.0379e^4 \quad \text{----- (3)}$$

For interval e (0.4, 1.0),

$$q_{11}= - 0.0064e + 0.8838e^2 – 0.0696e^3 + 0.082e^4 \quad \text{--- (4)}$$

Here, the eccentricity of 0.5 is chosen and the center frequency is taken as 2 GHz. By substituting the center frequency and eccentricity values in the above equations, the dimensions of the elliptical patch can be calculated. The T-slot length and width can be determined by parametric study.

Table 1: Design specifications of the proposed patch antenna

DESIGN PARAMETERS	VALUES
Semi major axis ‘a’	21 mm
Semi minor axis ‘b’	18.18 mm
Eccentricity ‘e’	0.5
Substrate thickness ‘h’	2 mm
Dielectric constant ‘ ε_r ’	4.4
Length of the T-slot ‘l’	18.4 mm
Width of the T-slot ‘w’	4 mm
Feed point	(6,3)

For TM_{11} mode, the theoretical value of resonant frequency for elliptical patch of semi major axis 21mm is found to be 2 GHz. This is the theoretical resonant frequency value for elliptical patch without T-slot. The multi frequency resonance can be obtained by properly designing the length and width of the T-slot and also the feed point of the probe. This plays a major role in optimizing the frequency.

3. SIMULATION AND RESULTS:

The simulation of the above designed antenna was performed using ANSOFT HFSS software. The FR-4 substrate size of 100mm*100mm*2mm is chosen as a dielectric material. Coaxial probe is used for exciting the patch. Figure 3 shows the S_{11} (dB) Vs frequency (GHz) for elliptical patch antenna without T- slot. Return loss (dB) is defined as that the difference in dB between power sent towards Antenna under Test (AUT) and power reflected [12]. The requirement for reflection co-efficient of wireless devices specifies 10 dB return loss bandwidth.

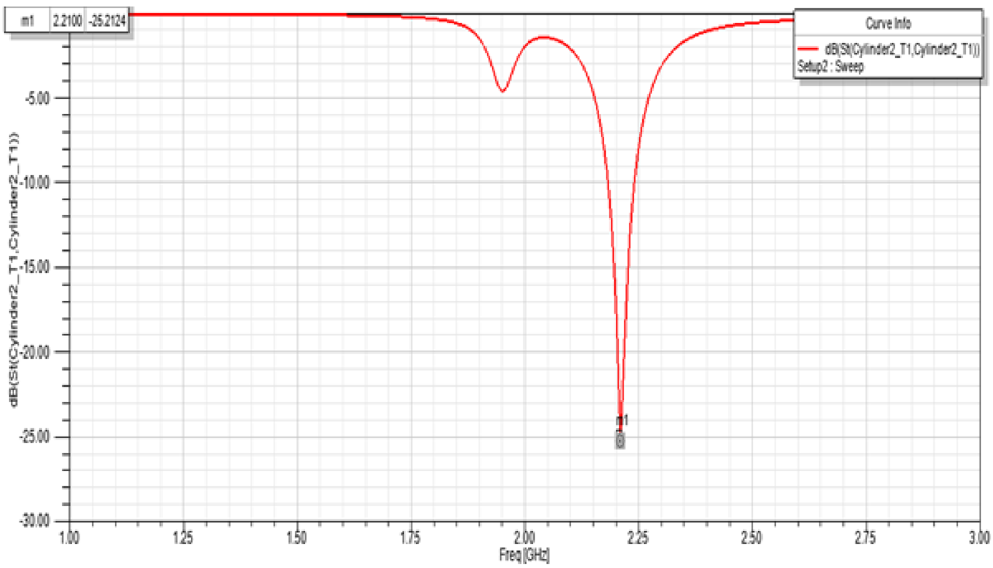

Figure 3: Return loss (dB) vs Frequency (GHz) for elliptical patch antenna without T-slot

The elliptical patch antenna without T-slot is simulated and its resonant frequency is 2.21 GHz and has a return loss of -25.21 dB. The elliptical patch antenna with T-slot is simulated as shown in figure 4. The dimensions of the T-slot are determined by parametric study in order to get optimized multi-frequency. The feed position of the patch is optimized for getting multi frequency. Table 2 and Table 3 show the parametric study of various lengths and widths of the T-slot.

Table 2: Length of the T-slot is varied with constant Width=4 mm

length (mm)	f_1 (GHz)	S_{11} (dB)	f_2 (GHz)	S_{11} (dB)	f_3 (GHz)	S_{11} (dB)
18.4	**1.57**	**-20.28**	**1.96**	**-16.8**	**3.4**	**-17.4**
18	1.58	-20	1.96	-15.6	3.41	-16
17	1.63	-19	1.97	-17	3.42	-12.9
16	1.66	-17	2.03	-15.7	3.5	-15

It is observed from Table 2 that as the length of the T-slot decreases, it increases the resonant frequencies.

Table 3: Width of the T-slot is varied with constant Length=18.4 mm

width (mm)	f_1 (GHz)	S_{11} (dB)	f_2 (GHz)	S_{11} (dB)	f_3 (GHz)	S_{11} (dB)
4	1.57	-20.28	1.96	-16.8	3.4	-17.4
3.5	1.57	-20.8	1.975	-17.53	3.4	-15.05
3	1.58	-23	1.97	-17	3.41	-11
2.5	1.58	-26	2	-18	3.43	-10

It is observed from Table 3 that as the width of the T-slot decreases, it increases the resonant frequencies.

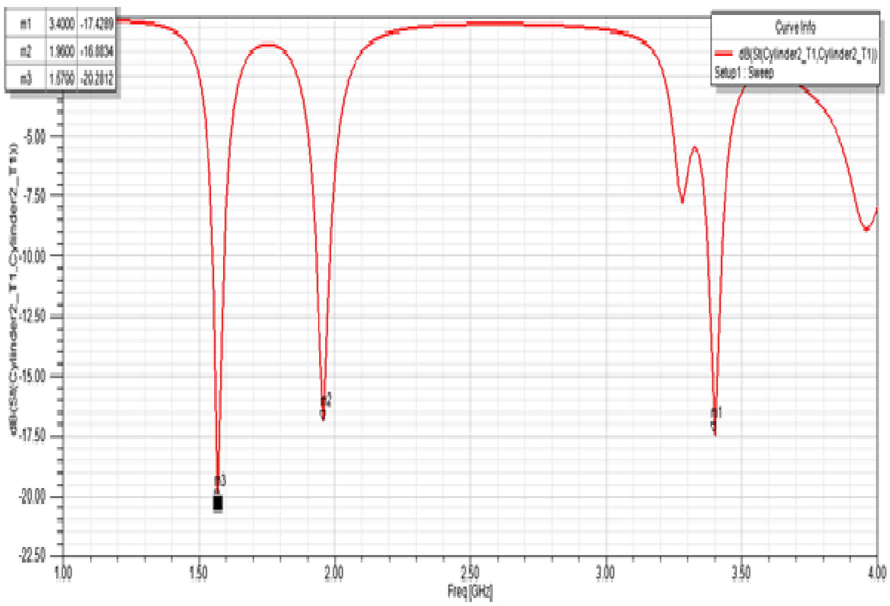

Figure 4: Return loss (dB) vs Frequency (GHz) for elliptical patch antenna with T-slot.

It is inferred from Figure 4 that the antenna exhibits return loss value –20.28 dB at 1.57 GHz, -16.88 dB at 1.96 GHz and -17.42 dB at 3.4 GHz. Figure 5,6 and 7 shows the radiation pattern for three different resonant frequencies, computed for multi frequency operation.

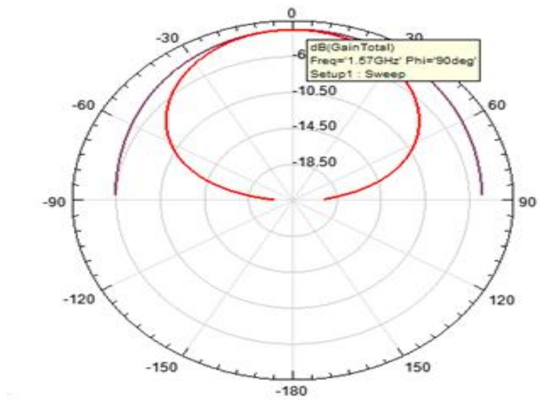

Figure 5: Radiation pattern at 1.57 GHz.

The Radiation pattern at 1.57 GHz frequency hasvery low gain of -3.5 dB and has a Half Power Beam Width of 84 degree.

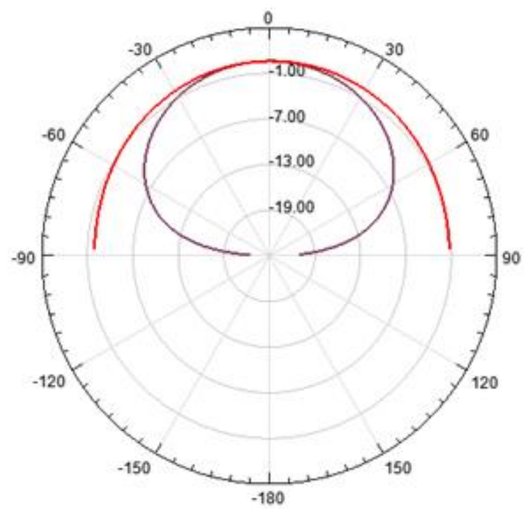

Figure 6: Radiation pattern at 1.96 GHz

The Radiation pattern at 1.96 GHz frequency has very low gain of -0.6 dB and has a Half Power Beam Width of 60 degree.

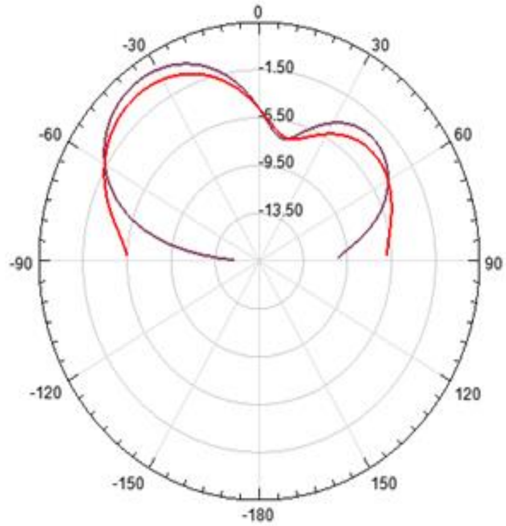

Figure 7: Radiation pattern at 3.4 GHz

The Radiation pattern at 3.4 GHz is a butterfly pattern and has minimum gain at bore side region.All these three frequencies provide very low gain. Hence, it can be used as a Receiver antenna.

Design 2:

The FR-4 substrate of thickness 2 mm is not available, so we have chosen thickness of 1.6 mm. The change of thickness of substrate has some effect on the resonant frequency. In order to obtain the predetermined frequency, length and width of the T-slot is varied.

TABLE 3: Width =4 mm

Length of the T-slot is varied with constant width:

length (mm)	f_1 (GHz)	(dB) S_{11}	f_2 (GHz)	(dB) S_{11}	f_3 (GHz)	(dB) S_{11}
17.8	**1.57**	**-31.06**	**1.96**	**-19.83**	**3.43**	**-21.76**
17	1.58	-18.73	1.94	-24.6	3.25	-15.74
16.5	1.63	-16.61	1.99	-21.06	3.41	-15.34
16	1.67	-14.26	1.99	-20.79	3.4	-12.28

As the length of the T-slot is increased, the resonant frequency is decreased.The length and width of the T-slot is chosen as 17.8 mm and 4 mm to obtain the optimized multi-frequency.

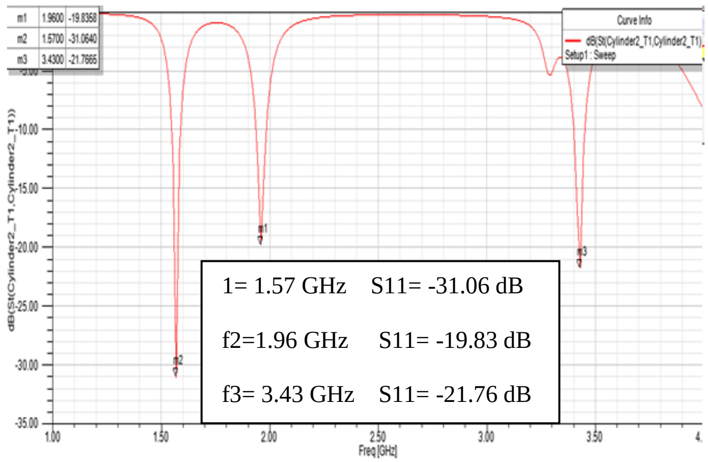

Figure 8: S_{11}(dB) vs. Frequency graph (GHz) for thickness 1.6 mm

It is inferred from the return loss graph for the thickness 1.6 mm,the antenna exhibits return loss value –31.06 dB at 1.57 GHz, -19.83 dB at 1.96 GHz and -21.76 dB at 3.43 GHz.

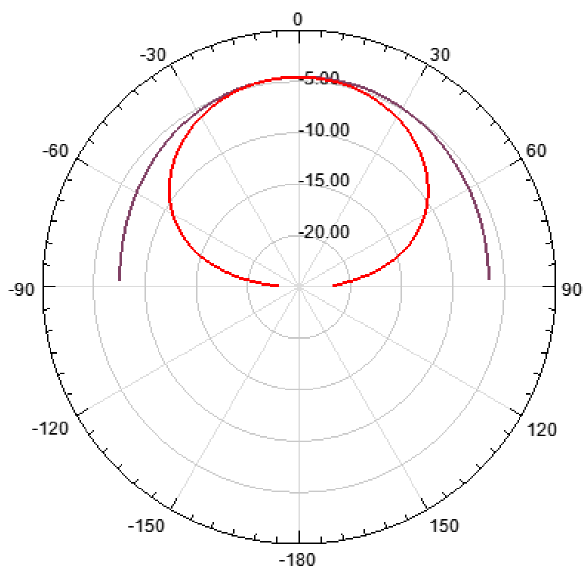

Figure 9: Radiation Pattern at 1.57 GHz

The radiation pattern for frequency 1.57 GHz shows that it has very low gain of -4.53 dB and Half Power Beam Width of 84 degree.

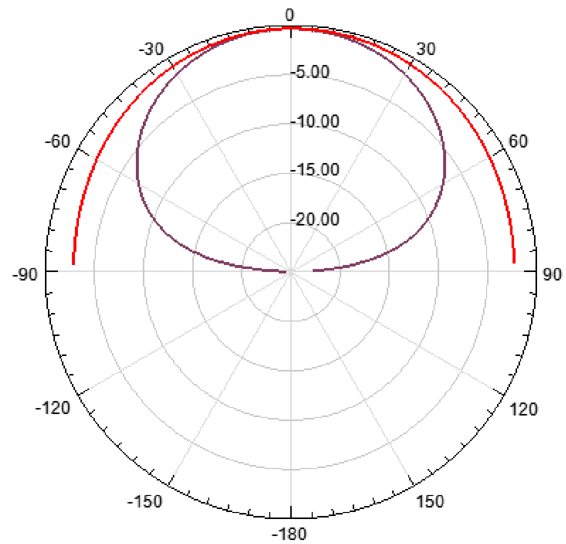

Figure 10: Radiation pattern at 1.96 GHz

The radiation pattern at 1.96 GHz has a very low gain of -0.3357 dB and Half Power Beam Width of 84 degree.

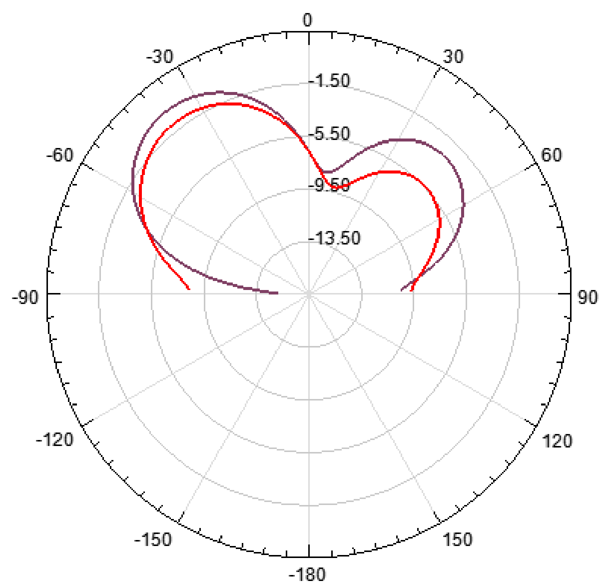

Figure 11: Radiation pattern at 3.43 GHz

The radiation pattern at 3.43 GHz shows that it has butterfly pattern

4. Experimental Results:

The FR-4 substrate of size 100*100*1.6 mm is chosen as a dielectric material. The elliptical patch of size 21*18.18 mm is fabricated on the dielectric material and a T-shaped slot is loaded on it. Figure 12 shows the top view of proposed antenna.

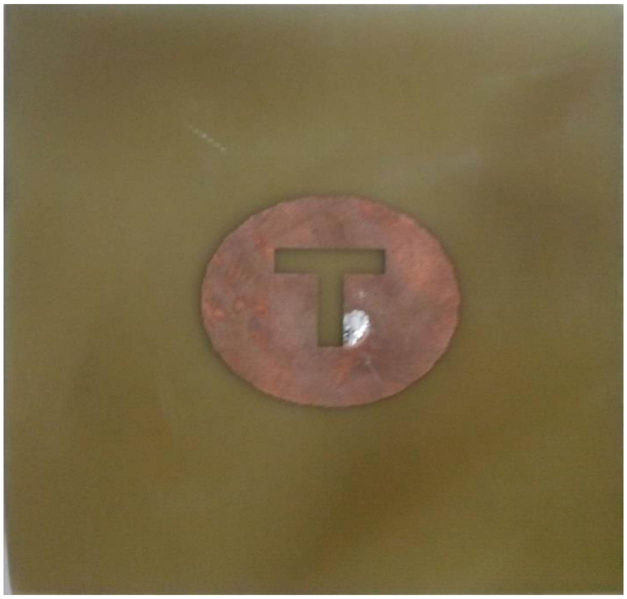

Figure 12: Top view of proposed antenna

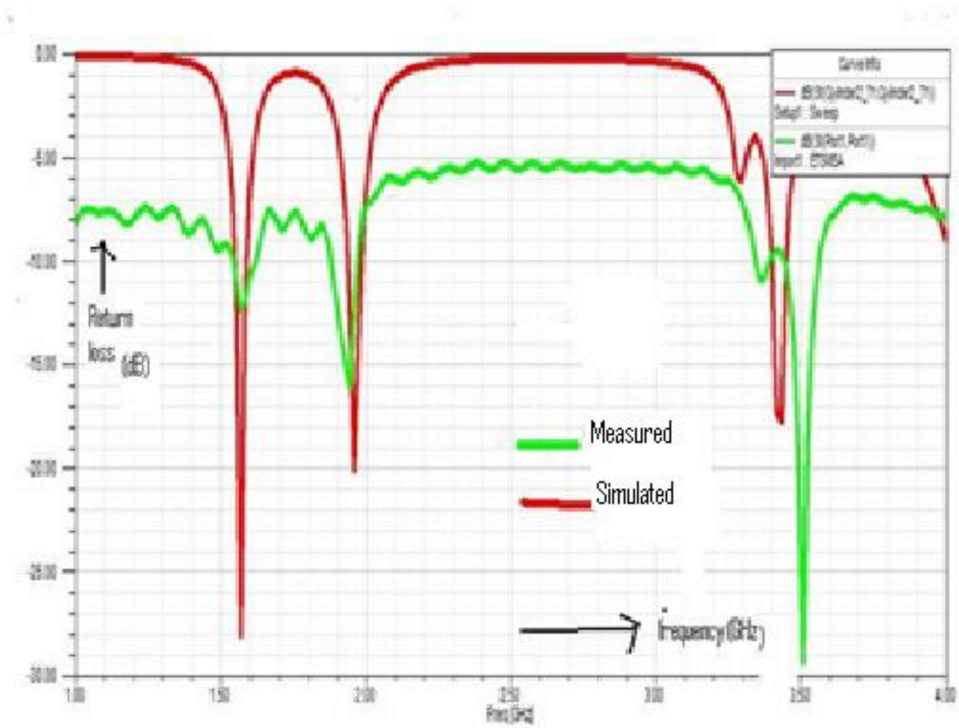

Figure 13: Return loss (GHz) vs Frequency(dB)

It is inferred from the graph that the elliptical patch incorporated T slot resonates at 1.58 GHz, 1.946 GHz and 3.5 GHz which has a return loss of -11.20dB, -16.36 dB and -19.09 dB.

Table 4. Comparison of simulated and measured output

PARAMETERS	SIMULATION OUTPUT	MEASURED OUTPUT
Frequency (GHz)	1.57 , 1.96 and 3.4	1.58, 1.946 and 3.5
Return loss (dB)	-31.06,-19.83 and -21.76	-11.26, -16.36 and -19.09

It is observed that the measured output has resonant frequency 1.58 GHz, 1.946 GHz and 3.5 GHz and return loss of -11.20 dB, -16.36 and -19.09 dB. The resonant frequencies of measured results slightly deviate from the simulation results. It may be due to substrate, connector losses and fabrication tolerances. It is inferred that the slot dimensions of the patch plays a major role in obtaining multi frequency operation

COMPARISION OF PROPOSED ANTENNA WITH OTHER ANTENNAS

Ref	Shape	Size (mm)	Freq in GHz	S_{11} (dB)	Feeding Method
Ref [4] 2009	Rectangle	39.6* 47.9	2.45, 3.4	-21.5 -13.2	Inset feed
Ref [5] 2013	Square	30* 30	1.18, 1.51, 3.35	-12.2 -17.3 -13.9	Coaxial feed
Ref [6] 2013	Circular	40	1.93, 2.17	-23.77 -35.16	capacitive Coaxial feed
Ref [7] 2014	Rectangle	23.4* 18.2	4.8, 6.81	-10.544 -19.483	Micro strip feed
Ref [8] 2015	Square Spiral	33.7* 33.7	1.58, 2.02, 2.47	-17 -25.4 -18	Coaxial feed
proposed antenna	Ellipse	21* 18.18	1.57, 1.96, 3.4	-20.28 -16.8 -17.4	Coaxial feed

In [4], multi-slotted antenna of size 39.6 mm * 47.9 mm is patched on the FR-4 substrate. The antenna is very large size and of very complicated structure than proposed antenna.

The square patch of size 30 mm*30 mm with T-slot and defective ground structure is discussed in [5]. The antenna resonates at multi-frequency. The structure is simple but it does not provide better return loss than proposed antenna.

In [6], the truncated circular patch of radius 40 mm is patched on the FR-4 substrate with double U slot. Air gap is introduced between the substrate and ground plane. Use of Airgap may increases the size of the antenna. This airgap is avoided in the proposed antenna.

In [7], the antenna of rectangular patch with size 23.4 mm * 18.2 mm is patched on the substrate and two T-slots are made on this patch. The antenna is fed by microstrip feed. But this antenna uses two T-slots to produce multi frequency.

In [8], the square spiral patch antenna with size 33.7 mm*33.7 mm is patched on the FR-4 substrate. The antenna is of very large size and complicated design as compared to proposed antenna.

The proposed antenna is an elliptical shape of semi major axis 21 mm and semi minor axis 18.18 mm with T-slot on the elliptical patch. The antenna is fed by coaxial feed. There is no air gap. FR-4 substrate of thickness 2 mm with dielectric constant 4.4 is chosen. The antenna structure is simple and provides better return loss.

CONCLUSION:

From the analysis, it is concluded that the proposed antenna resonates at three different frequencies. The frequencies are 1.57 GHz, 1.96 GHz and 3.4 GHz which has return loss of -20.28 dB, -16.8 dB and -17.4 dB respectively. The frequencies can cover applications such GPS, 4G LTE and WiMAX. Simulation and measurement results are presented for validation of the design and agree with each other. Hence, a compact multi-frequency MSA is designed for GPS, 4G LTE and WiMax applications.

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